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13. ABSTRACT (Maximum 200 words)

The goal of the research effort in the DataMan Project is the development of novel wireless information services, location-dependent protocols such as geographic routing, and low energy protocols for wireless networks and devices.
In each of the areas we have made progress and several results to report. First, the problem of efficient energy management and bandwidth utilization has been addressed using the concept of Meta-Channel designed for dissemination of information to wireless mobile users. Several protocols for low energy dissemination have been designed and demonstrated.
Location dependent messaging has been made possible by the concept of Geographic Routing which has been designed and deployed to enable routing of messages to specific geographic areas for conveying location-dependent information. A complete user guide for geographic routing has been prepared.
Finally, mechanisms for environment aware adaption in applications and protocols have been completed.
Since, mobile users encounter widely varying network characteristics, there is a need for dynamic adaptation. To this end, we have designed a new family of environment-aware protocols.

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1 Statement of the problem studied

Wireless communication environment constitutes the "first mile" of the information infrastructure. Many, if not most, of the mobile clients of the National and defense Information services are portable, battery powered terminals communicating with the fixed network over wireless links. Providing information services in a mobile environment requires fundamental changes to commonly available client server protocols. Specifically, in this project, the problems studied to make mobility a first class object in the information infrastructure were:

- Interoperability and adaptability to different networking environments ranging from a high bandwidth wireless LAN environment to a low bandwidth cellular environment and a hybrid satellite or space based communication links.
- Energy efficient data access for terminals running on selfcontained energy sources such as batteries.
- Support for mobility and disconnection at all levels of the protocol hierarchy
- Support for location dependent services and location dependent routing of information.
- Support for environment aware abstractions that will allow applications to adapt to varying conditions of communication and resource availability.

2 Summary of the most important results

1. Energy efficient broadcast algorithms
   - Data organization and layout methods to provide a totally *self defined* broadcasting channel called the meta channel which provides both directory and data and enables the client to selectively tune to wanted data.
   - Adaptive algorithms to decide which data items are to be periodically broadcast and which are to be provided on demand and for which items to provide just cache invalidation reports.
   - Data indexing methods using multicast addresses to provide fine grain filtering capability for the clients.
2. Indirect protocols Wireless and mobility have impact on how end-to-end protocols are structured. Existing end-to-end protocols assume that the underlying network infrastructure is to a large extent homogeneous. However, a wireless link is drastically different in terms of reliability and available bandwidth compared to a fixed link. Also, the end point of a connection changes its network attachment point as a mobile host moves in the network. In, we argue that there is a need to make mobility explicit at every level of the protocol stack. To this end, we proposed a concept of indirect connection. Here, an end-to-end connection is split

into two: one connection for the wireless, and the other for the fixed part. With this type of connection, we can tune and optimize the protocol for the wireless link without modifying anything on the fixed network. This approach had significant impact on the design of protocol and services for wireless networks resulting in a client-proxy-server architecture; a commonly used architecture for wireless services. Extensions to this work has resulted in a RPC model for mobile hosts, performance improvements in TCP for wireless (both local area and wide area) networks.

3. Environment aware protocols

   In mobile computing, factors such as varying resource availability of devices, bandwidth, battery power, results in an environment of changing resource constraints. An application in such as constrained environment must react to these changes so that available resources are properly utilized and at the same time provide reasonable utility to the user of the application. A new architecture that provides feedback about the environment to the components of the application was designed. The utility of this architecture was shown in an environment of a network sub system that adapts to available bandwidth in the network when new hardware components are added or removed that can provide or remove access to wireless networks. Application adaptation is now a very important area of research in mobile computing. Adaptation in components, operating systems, and applications are being proposed by various researchers.

   An environment aware API was introduced to cope with the availability of variety of communication devices offers a choice among networks with vastly different characteristics. No single protocol or application can be expected to perform well over all these networks. A mobile host is likely to encounter these different networks and needs to adapt accordingly. The problem of adapting to a changing network environment is further complicated, because changes in network conditions are usually transparent to higher layers of the protocol stack. In order to allow automatic adaptation of applications and protocols, awareness of link conditions and network environment is necessary. The API developed allows for a uniform mechanism based on ICMP messages for providing information about the environment to the protocol stack. Protocols can adapt to changes in the environment, and in particular, allow dynamic fine tuning of some of the well known protocols such as UDP and TCP. Performance measurements demonstrate that our framework imposes little overheads and improves protocol performance under changing network conditions.

4. Geographic routing and addressing

   GPS based messaging: addressing and routing allows routing and delivery of messages to physical regions rather than individual users. A geographic message (geo-message) is a message addressed to a given geographic area (specified as a polygon, circle etc). Clients which are equipped with the GPS cards can use the GPS position to filter messages which are directed to the area in which the client is currently located. GPS card (or any other method of

determining location such as special beacons) can also be used in order to identify network services located within a particular distance from the mobile client. We have proposed three different routing methods for geo-messages: one based on a new routing software working in the IP level, another using the multicast protocols and finally the third method which extends the concept of domain name services with geographic information. Additionally, we have proposed different methods to assure quality of service in case a client is temporarily disconnected. Finally, we have proposed solutions to integrate geo-casting with multicasting. A mechanism to tunnel geographic messages over existing network to create geo-bone was designed and implemented.

3 List of all publications and technical reports:

1. "A Conceptual Framework for Network Adaptation", B. R. Badrinath, Armando Fox, Leonard Kleinrock, Gerald Popek, Peter Reiher, M. Satyanaryanan, In ACM/Baltzer Journal on Mobile Network and applications, special issue on software architectures for mobile applications, Vol. 5, No. 4, December 2000, pp. 221-231.

2. Tomasz Imielinski and Julio C. Navas, "Geographic Addressing, Routing, and Resource Discovery with the Global Positioning System". Communications of the ACM Journal. 1999.

3. "An architecture for exporting environment awareness to mobile computing applications," Girish Welling and B. R. Badrinath, IEEE transactions on Software Engineering, Vol 24., NO 5., May 1998, pp. 391-400.

4. "Data on Air: Organization and access," T. Imielinski, S. Viswanathan, and B. R. Badrinath, IEEE Transactions on Knowledge and Data Engineering, Vol. 9, No. 3, May/June 1997, pp. 353-372.

5. "Implementation and performance evaluation of indirect TCP", Ajay Bakre, and B. R. Badrinath, IEEE transactions on Computers, Vol. 46, Number 3, March 1997, pp. 260-278.

6. " A framework for delivering multicast messages in networks with mobile hosts ," A. Acharya and B. Badrinath, ACM-Baltzer Journal on Mobile Networks and Applications, Volume 1, No. II, 1996, pp. 199-219.

7. "Analysis of a mobile-assisted adaptive location management strategy," ACM-Baltzer Journal on Mobile Networks and Applications, R. Yates, C. Rose, S. Rajagopalan and B. Badrinath, Volume 1, No. II, 1996, pp. 105-122.

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12. "On accommodating mobile hosts in an integrated services packet network," Anup Talukdar, B. R. Badrinath, Arup Acharya, In IEEE Infocom' 97, Kobe, Japan, April, 1997, pp. 1048-1055.

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15. "Multiversion reconciliation for mobile databases," Sirish Phatak and B. R. Badrinath, In Proceedings of the ICDE 99, March 1999, pp 582–589.

16. "Conflict resolution and reconciliation in disconnected databases," Sirish Phatak and B. R. Badrinath, In MDDS 99, September 1999, pp. 76-81.

17. "Data partitioning for disconnected client-server databases," Sirish Phatak and B. R. Badrinath, In Proceedings of the MobiDE, August 1999, pp. 102-109.

18. "Data warehousing alternatives for mobile environments," Ion Stanoi, Divy Agrawal, Amr Abbadi, Sirish Phatak and B. R. Badrinath, In Proceedings of the MobiDE, August 1999, pp. 110-115.

19. Julio C. Navas and Tomasz Imielinski, "On reducing the computational cost of Geographic Routing" ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom'2000). February 25, 2000.

20. Tomasz Imielinski and Samir Goel, DataSpace - querying and monitoring deeply networked collections in physical space, Proceedings of International Workshop on Data Engineering for Wireless and Mobile Access (MobiDE'99), Seattle, Washington, August 20, 1999.

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31. "Exporting Environment Awareness to Mobile Applications", Girish Welling and B. R. Badrinath, Technical Report LCS-TR-270, Department of Computer Science, Rutgers University, July 1996.

4 SCIENTIFIC PERSONNEL supported

4.1 Faculty

1. Tomasz Imielinski (PI)
2. B. R. Badrinath (co-PI)

4.2 Students

1. S. Vishwanathan (PhD Student)
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4. Julio C. Navas (PhD Student)
5. Samir Goel (PhD Student)
6. Pedrum Mohageri (undergraduate student)

5 Report of INVENTIONS

1. Energy efficient indexing for broadcast protocols in wireless networks
2. Metachannel directory for broadcast data in wireless low power environments
3. Indirect TCP protocol for improving performance of TCP over wireless links.
4. Environment aware API for application and protocol adaptation.
5. Polygon approximation techniques for geographic routing
6. Protocol encapsulation for geocasting (GeoOSPF, GeoRIP, GeoBP) The Geocast protocols that modified existing IP protocols are the following: GeoOSPF, GeoRIP, and GeoBP. These protocols were chosen because they offered a contrast in the amount of information that had to be gathered and stored in a routing database before packet forwarding could be performed. The amount of information gathered before packet forwarding can commence in all of these protocols has a direct influence on the number of prune messages that subsequently have to be sent and processed in order to clean-up the routing tree that results from forwarding the first geocast message.
7. GPS-Multicast protocol (GPS-Multicast over PIM-Sparse and DVMRP) These geocast protocols leverage existing protocols by running over them are the following: GPS-Multicast over PIM-Sparse and GPS-Multicast over DVMRP. PIM- sparse and DVMRP were chosen because they offered a contrast between control-driven and data-driven versions of multicast for the geographic routing protocol called GPS- Multicast to run over.